Information and measurement control systems for technological processes in the grain processing industry

1st Kalandarov Palvan Iskandarovich
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers
Tashkent,Uzbekistan
eest_uz@mail.ru

2nd Mukimov Zieviddin Mamurovich
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers
Tashkent,Uzbekistan
mukimov63@inbox.ru

3rd Avezov Nodirbek Egambergonovich
Urgench branch of the Tashkent University of Information Technologies
Urgench, Uzbekistan
nodav@list.ru

4th Abdullaev Husniddin Hussein ugli
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers
Tashkent,Uzbekistan
husniddin.abdullayev9395@gmail.com

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***Abstract*— In this paper, we present a method to obtain the measurement results do not depend on the resistance-controlled material, and discusses the influence of the effect of active compensation of losses on the frequency of the generator, which serves as the synthesis of new measuring devices block moisture control pastes.**

To improve the efficiency of technology, organization of control, quantitative accounting of raw materials, products, process control, it is necessary to introduce an automated control system for managing technological processes. For this purpose, mathematical models of the dielectric permittivity of heterogeneous wet systems and ways to increase the reliability and accuracy of the results of monitoring the humidity of materials by the dielkometric method using information-measuring systems are analyzed. The mathematical description of the study of the effect of compensation of active losses on the frequency of the generator for humidity control devices of granular materials and the design of the high-frequency method and the design of humidity control devices of capacitive measuring transducers based on it are considered.

Keywords— management, information systems, automatic control system, humidity control, measurement information, frequency, information processing.

I. Introduction (*Heading 1*)

Control of the technological process, as well as objects in the form of automatic regulatory action, is possible only if there is a measurement transformation and data is obtained about the required informative parameter that characterizes the course of the technological process or the state of the object under study. The design of humidity control devices for the materials under study plays an important role in the construction of automatic control systems, as well as control over the flow of technological processes and production of automated control systems, where primary measurement information is required in a form convenient for further transformation.

Problem statement

The considered granular materials and products of their processing, used in the food and confectionery industry, unlike other types of it, has a humidity of up to 18%, contains salt, and therefore the quality factor of the contour of the measuring generator of humidity control devices does not exceed Q=1.1. Ensuring such a Q-factor of the measuring generator circuit requires the use of an operating frequency f=10 MHz [1].

Theoretical background

A large number of works are devoted to the research of information and measurement systems and the design of humidity control devices [1, 2, 3]. More detailed studies can be noted the works of E. S. Krichevsky [4] where the author of devices synthesized on the basis of frequency beats calls F-meters. The transmitting parts of these devices, i.e. the circuits include primary measuring converters, auto generators and information preprocessing units. With the help of two communication lines, the transmitting part of the circuit is connected to a receiver that divides the frequencies of the measuring and correcting channels. The generators have an initial frequency of f = 0.5 MHz and are assembled according to the Meissner scheme on high-power field-effect transistors with an inertial element of automatic displacement in the gate circuit.

Figure 1 shows the dependences of the ratio of the main frequency of the generator ω to the resonant frequency of the circuit ω0 from R[$\omega/\omega_0 = \varphi$ (R)]. Curves 1-3 were removed in the absence of automatic displacement (R_1 =0; C=0), with three different values of the constructed gate offset Ez, curve 4 corresponds to Ez = 0 and the choice of R_1, C_1 according to the method discussed below.

The abscissas of the left ends of the curves correspond to the values of R, at which the oscillation failure occurs. The data in Fig. 1 clearly show the presence of the effect of compensation for the influence of active losses on the main frequency of the generator, achieved with the appropriate choice of parameters of the automatic offset circuit. The theoretical analysis of this method, which is extremely important for measuring humidity, will be carried out based on the following stress equations on the circuit Uk and the gate Uz, written in symbolic form:

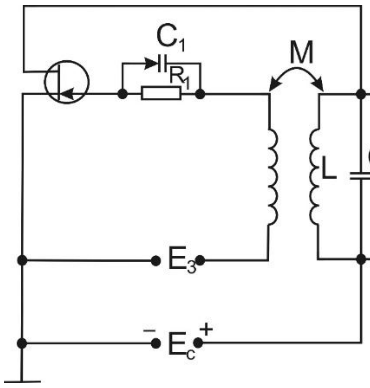

Fig. 1 Schematic diagram of a high-frequency generator implemented according to the Meissner scheme

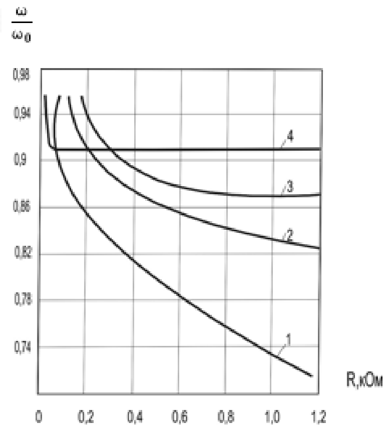

Fig. 2 Dependence of the generator frequency on the active resistance of the circuit.

$$U_к = Z(P)\cdot i_c\,(U_з) = (LC_p{}^2 + \frac{L}{R}\cdot P+1)^{-1}\cdot L_p\cdot i_c(U_з) \quad (1)$$

$$U_з = \frac{M}{L}U_к - \frac{R_1}{1+PR_1\;C_1}\,i_з\,(U_□) + E_з \quad (2)$$

Here ic and iz are the drain and gate currents that depend only on Uz, assuming that the field-effect transistor operates in the saturation mode at the Ec voltage [4, p. 36-37], the inductive resistance in the gate circuit is not taken into account, since in the operating frequency range of the EMF, self-induction is small compared to Ez and the voltage on the R_1 C_1 chain.

The current-voltage characteristics of ic and ip are approximated based on:

$$I_c(U_з) = \begin{cases} 0 \\ ½\,\mathrm{So}\,(\mathrm{U}з - \mathrm{Uo})^2(\mathrm{U}_1 - \mathrm{Uo})^{-1} \\ \mathrm{SoU}з - ½\cdot\mathrm{So}(\mathrm{U}_1 + \mathrm{Uo}) \end{cases}$$

$U_з \le Uo$
$Uo < Uз \le U_1$ (3)
$Uз \ge U_1$

$$I_з(U_з) = I_{зо}\left[\exp\left(\frac{gUз}{кT}\right) - 1\right] \quad (4)$$

Where: So is the steepness of the linear part of the current-voltage characteristic ic(Uz);

Uo – cut-off voltage;

Izo-reverse gate current at saturation;

g is the electron charge;

k is the Boltzmann constant;

T is the absolute temperature.

Let's go to (1) and (2) to dimensionless variables:

$X = U_з(U_1\text{-}U_o)^{-1}$; $Y = U_k(U_1\text{-}U_o)^{-1}$; $\tau = t\cdot\omega_o$, $\varepsilon = MS_o\,\omega_o$

$l = \frac{R}{L}$; $\mu = \frac{L\,\omega o}{R}$; $\Theta = R_1C_1\,\omega_o$;

$\beta = R_1I_{зо}(U_1\text{-}U_o)^{-1}$

$\lambda = g(U_1\text{-}U_o)(kT)^{-1}$; $X = U_o(U_1\text{-}U_o)^{-1}$;

$e = E_з(U_1\text{-}U_o)^{-1}$;

Let's introduce the functions :

$$F(x) = \frac{i_c\,[x(U_1 - U_o)^{-1}]}{S_0\,(U_1 - Uo)} = \begin{cases} 0 \\ \frac{1}{2}\,(x - \bar{x})2\,; \\ x - \bar{x} - ½ \end{cases}$$

$x \le \bar{x}$
$\bar{x} \le x\,(\bar{x}+1)$ (5)
$x \ge (\bar{x}+1)$

$$f(x) = i_з[x(U_1\text{-}U_0)^{-1}]\;I_{зо}^{-1} = \exp(\lambda x)\text{-}1 \quad (6)$$

In the new variables (1) and (2), they will take the form of a system of ordinary differential equations.

$$P\left(\frac{d}{d\tau}\right)\cdot y = \frac{d^2y}{d\tau^2} + \mu\,\frac{dy}{d\tau} + y = \frac{\varepsilon}{\alpha}\,\frac{d}{d\tau}\,F(x) \quad (7)$$

$$(1 + \theta\frac{d}{d\tau})x + \beta f(x) = \alpha\,(1 + \theta\frac{d}{d\tau})\,y + e \quad (8)$$

By acting on (8) with the operator P (d/ (dτ)) and using (7) we come to a third-order equation for x (τ):

$$(1 + \theta\frac{d}{d\tau})\cdot P\left(\frac{d}{d\tau}\right)x + \beta\,P\left(\frac{d}{d\tau}\right)\cdot f(x) - \varepsilon(1 + \theta\frac{d}{d\tau})\cdot\frac{d}{d\tau}\,F(x) - e = 0 \quad (9)$$

For an approximate representation of the quasi-harmonic self-oscillations described by equation (9), we use the harmonic balance method. In view of the diode detection taking place in the gate circuit, the solution should be sought in the form of asymmetric oscillations:

$$X(\tau) = X_0 + X_1\cos\Omega\tau \quad (10)$$

Decomposing the functions into a Fourier series by cosines, we get:

$$f = (x_0 + x_1\cdot\cos\varphi) = e^{\lambda x_0}\,I_0\,(\lambda x_1) - 1 + 2\sum_{n=1}^{\infty} e^{\lambda x_0}\,I_n\,(\lambda x_1)\cdot\cos n\,\varphi \quad (11)$$

$$F(x_o + x_1\cdot\cos\varphi) = \sum_{n=0}^{\infty}[2\,x_1\gamma_k\,(1,\varphi) + \frac{x_1^2}{2}[\gamma_k(2,\overline{\varphi}) - \gamma_k(2\,,\varphi_1)]\cos x\,\varphi \quad (12)$$

where: In is the modified Bessel functions (Bessel functions of imaginary argument); k(P,φ), the so – called expansion coefficients (kP) thus: $\overline{\varphi} = \arccos(\bar{x}\text{-}x_o)\cdot x^{-1}$, the cutoff angle, and $\varphi_1 = \arccos\,(1\text{-}x_o+\bar{x})\;x_1^{-1}$.

In accordance with the method of harmonic balance, equating to zero the sum of constant components and the amplitudes of the first harmonics, when you stand (11)-(12) in (9) , we arrive to the following system of equations for the variables x_o, x_1, и Ω:

$$\begin{cases} Xo + \beta fo(Xo, X1) - e = 0 \\ \Omega 2(X_1 + \beta f1 + X_1\mu\theta - \varepsilon\theta F_1) - X_1 - \beta f_1 = 0 \\ X_1(\mu + \theta - \Omega^2\theta) + \mu\beta f_1 - \varepsilon F_1 = 0 \end{cases} \quad (13)$$

where the coefficients of the expansions (11) and (12) are denoted by dk (Xo ,X_1), F (Xo,X).

Let's start by considering the case when there is no automatic offset, i.e. R1=0 and C1=0. Then β=θ=0 and from (13) that X_0 = e, Ω^2=1, $\mu x_1 = \varepsilon F_1(e,x)$.

Thus, in the first approximation, the oscillations in this case are isochronous (ω=ω0). In order to explain the significant decrease $\Omega = \frac{\omega}{\omega^0}$ for small μ (large R) observed in the experiment (curves 1-3) in Fig. 2, it is necessary to take into account the influence of nonlinear distortions, i.e. higher harmonics of the solution X (τ). β=θ=0, equation (9) is of the second order and the correction to the frequency due to nonlinear distortions can be obtained from the expression

$$\Omega^2 = \frac{\omega^2}{\omega_0^2} = 1 - \sum_{k=2}^{\infty} \frac{\kappa^2}{\kappa^2 - 1} \cdot \frac{\varepsilon\gamma_n^2 (e,x)}{x_1^2} \quad (14)$$

Thus, due to the higher harmonics, the fundamental frequency decreases [5].

Calculations show that, in accordance with the experimental data, this decrease is noticeable only at large R, when the oscillation amplitude is large and the nonlinearity of the current-voltage characteristic ic(Uz) significantly affects the magnitude of the higher harmonics.

For small R, the amplitude of the oscillations decreases rapidly, and they occur in the section of the current-voltage characteristic that can be approximately considered linear. This leads to the fact that there are practically no higher harmonics and $\Omega \approx 1$[6].

Let us now consider the case when R1, C≠ 0. In this case, the first of the equations (13), taking into account the explicit form f_0 (x_0, x_1), leads to the following relationship between the oscillation amplitude and the constant component of the gate-source offset Xo

$$I_o (\lambda X_1) = e^{-\lambda X_0} [1 + \frac{1}{\beta} (e - x_o)] \quad (15)$$

Showing that due to the detecting property of the gate circuit, the amplitude is automatically adjusted.
Further, by combining the second and third equation (13), it is easy to obtain the following relation for Ω:

$$\frac{1-\Omega^2}{\Omega^2} = (\Omega^2 - 1) \cdot \frac{\theta^2 \ x_1}{x_1 + \beta f_1} - \mu \frac{\beta\theta f_1}{x_1 + \beta f_1} \quad (16)$$

From which it clearly follows that Ω>1. For small values of $\beta\theta$, an approximate dependence follows from (16):

$$\Omega^2 \approx 1 + \frac{\beta\theta f_1}{(\theta^2+1)x_1 + \beta f_1} \quad (17)$$

It follows from (16), (17) that now $\omega \neq \omega_0$ is already in the first approximation, i.e. without taking into account the higher harmonics, and the frequency shift occurs in the direction of increase. Since the higher harmonics still cause frequency deviations to decrease, frequency compensation occurs, which explains the frequency stability when the active resistance of the circuit changes [7, 8].

For the third-order equation (9), the formulas for calculating the frequency correction due to higher harmonics are too cumbersome for practical application. Nevertheless, for the initial choice of parameters, it is possible to estimate this correction using expressions (14), and then from (17) select β and θ from the conditions for its compensation. . Subsequent refinements of the parameters for optimal frequency stabilization are carried out experimentally [9]. The results of the studies shown in Fig. 2 (curve 4) correspond to the following values of the constants:

C = 2718 pF, L = 6, 58 MCG, L1 = 3.7 mh, C_1 = 200 pF, R_1 = 1.75 mOm.

As an active element of the generator, a field-effect transistor KP 90 SV is used with the following parameters of the current-voltage characteristic:

$$S_o = 100\frac{MA}{B}, U_o = -10 B, U_1 = -7B$$

Curves 1-3 correspond to constant displacements of Ez, equal to-3.5 V, - 4.5 V, - 5V, respectively.

Result

The results of these studies conducted for the first time and are new for material humidity monitoring devices and provide the most reliable way to obtain measurement results that do not depend on the resistance of the controlled material, but only on its capacity [10, 11, 12]. According to the results of the above theoretical and experimental studies in high-frequency moisture measurement, when changing various physical parameters of the controlled material, it is necessary to give preference and use the capacity as a parameter control while minimizing the active resistance, and for such products such as margarine sold on the basis of free fatty acids and changing salinity, a different formulation of the problem is possible, It is aimed at studying the connections between the active resistance that are the object of measurement, i.e., it means the material placed in the sensor with electrodes [14, 15].

The results of the conducted studies have shown [16,]:

- the ability to synthesize new measuring blocks of devices for monitoring the humidity of the material, providing measurements of low moisture content with high accuracy;

- optimize for such a system of sensors of the coplanar type in the form of electrodes;

- the ability to measure the moisture content of the material directly in the bundles using a needle sensor;

- the absence of the necessary introduction of influencing factors and corrections to the measurement results in the real measurement range;

As a result of the research, the actual task of synthesizing a high-frequency device for monitoring the humidity of pasty materials with high expressiveness of control and satisfying the practice with metrological characteristics is solved.

The obtained results were tested in the conditions of the grain processing industry in the conditions of JSC "Galla-Alteg" .

Discussion

According to the method given in [16] and in accordance with the recommendations [17], we have developed a microwave moisture meter [12, 17] intended for use in systems for monitoring grain technological processes by humidity in production conditions. The advantage of the microwave method is its low sensitivity to the physical and mechanical properties of the substances and materials under study, which makes it possible to analyze media with large active losses.

Also, a noticeable advantage in the accuracy of the microwave method over the RF method remains. However, the implementation of microwave moisture meters is significantly more complex than RF moisture meters, since it is much more difficult to generate an ultrahigh-frequency electric field of sufficient power than the RF field. The method based on the physics of properties in ultrahigh frequency (microwave) electromagnetic fields is equal to the frequency range from 5.107 to 5.1010 Hz. [18].

Conclusions

The creation of microwave moisture meters based on this method, capable of working in difficult conditions, where humidity control and regulation must be provided at all stages, from the procurement of raw materials to the storage and shipment of finished products, is one of the urgent tasks in the field of moisture measurement [19]. The conducted studies have shown that the dependences of the dielectric properties of grain and grain crops on their humidity in the microwave range have the same appearance and are very close to each other. These circumstances allow us to create a universal microwave moisture meter for agricultural products on the basis of the built device [20].

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